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Jessica Doss
TransPerfect Translations
601 13th Street, NW
Suite 320 North
Washington, DC 20005

Sworn to before me this
13th day of December, 2005

Signature, Notary Public

Lisa Sherfinski
Notary Public, District of Columbia
My Commission Expires 01-01-2008

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71 Applicant(s): THOMSON CSF SOCIETE ANONYME – FR.

72 Inventor(s): Delage, Sylvain; Floriot, Didier; Blanck, Hervé; and Roux, Pascal.

73 Holder(s):

74 Agent: THOMSON CSF

54 THERMALLY STABILIZED SEMICONDUCTOR COMPONENT WITH BIOPOLAR TRANSISTORS

57 The invention pertains to a semiconductor component with bipolar transistors. This component is thermally stabilized by the presence of ballast resistance R_B
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and additionally, is assembled in parallel with a condenser C_B.

Application: Amplifiers, oscillators.

[see source for diagram]

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THERMALLY STABILIZED SEMICONDUCTOR COMPONENT WITH BIPOLAR TRANSISTORS

The invention applies to semiconductor components with bipolar transistors, intended to function specifically in microwave frequencies as power amplifiers or tunable oscillators.

In general, creating microwave power components requires the use, in parallel, of a set of elementary bipolar transistors. One kind of architecture currently being developed is the one illustrated in Figure 1, in which the various emitters on the various transistors are connected to an "emitter bus" (bE) via metal conductive ribbons, where the various bases are connected to a "base bus" (bB) via metal conductive ribbons, and the chemical contacts of the elementary component collector are connected by an air bridge-type metal ribbon spanning the elementary components, where the various collectors are connected to a "collector bus" via the legs of a collector bridge (PC).

However, in these power mechanisms, thermal runaway problems arise due to the deviation in the current-voltage characteristic in the junction between the emitter and the base of the transistors (on the order of -1.5 mV/K). This deviation in the current-voltage characteristic in the emitter-base junction results in a situation, for example, for a fixed base current, in which the hottest areas drain practically all of the base current and therefore the collector current. As the dissipated power increases in the component, an increasingly marked thermal gradient develops. The hottest central pins drain more current than the pins on the ends. In a chain reaction, only the central pin ends up functioning as a conductor.

This phenomenon has traditionally been corrected by adding ballast resistance in series to each of the emitter pins in the power component. Due to the drop in potential in these resistances, depolarization occurs in the emitter-base joints that is just as strong as the emitter current passing through them is high. This results in a counter-reaction regulating the distribution of the current in the power component, which decreases the thermal runaway.

However, the ballasting operation at the emitter level introduces another disadvantage, which the semiconductor component described in the invention proposes to resolve.

Indeed, in all of the current curves for the collector I_C as a function of the voltage V_{ce} for an imposed base current I_b, as illustrated in Figure 2, a waste voltage V_{CE} min appears, which corresponds to the transition from saturated behavior to linear functioning. The component can be used between this voltage and the breakdown voltage V_{CE} max. Thus, the waste voltage increases with the resistance Re in the emitter. Ballasting the emitter therefore decreases the V_{CE} max–V_{CE} min voltage range, in which the semiconductor component may function, which thus affects the added power yield of the component. Moreover, the increase in the emitter resistance implies a loss, by Joule effect, in this element, which also deteriorates the added power yield. Furthermore, creating ballast resistance for microwave frequency applications imposes both low values (approximately five ohms) and a great compactness (30 µm x 8 µm) to limit the propagation time and the appearance of stray inductance. In practice, the creation of such resistance is particularly difficult, and only metal resistance can be used; even then, there is a risk of electromigration phenomena occurring (current density on the order of 10^6 A cm^{-2}).

In order to correct these phenomena, the invention proposes to avoid the thermal runaway problem by ballasting the semiconductor component using a resistance R_B mounted in series on the base. To compensate for the loss of current gain at high frequencies, and particularly in microwave frequencies, due to the presence of a ballasting resistance, the resistance R_B is also mounted in parallel with a condenser C_B, and the set (R_B, C_B) is then mounted in series with the base.

More specifically, the purpose of the invention is a semiconductor component with at least one bipolar transistor including an emitter (E), a base (B) and a collector (C), characterized in that the base (B) is connected in series with a resistance (R_B) – condenser (C_B) set, mounted in parallel; the bipolar transistors used in the semiconductor component

described in the invention can advantageously be bipolar transistors with a heterojunction (TBH), due to the excellent performance they make it possible to attain, as will be explained below. Preferably, the semiconductor component includes several transistors (Ti) in parallel, built on a substrate (S), in which the bases (Bi) of the transistors (Ti) are connected to a base bus (bB) via the circuits (resistance R_{Bi}, condenser C_{Bi}). The emitters (Ei) are connected to an emitter bus (bE), and the collectors (Ci) are connected to one another by a collector bridge (PC).

The substrate (S) can advantageously be a material III-V- or silicon-based semiconductor substrate that is homogenous or an insulated type semiconductor.

The purpose of the invention is also to provide a process for creating a semiconductor component with at least one bipolar transistor (Ti), made by stacking at least one layer (I_c) in which the collector (Ci) is made of (Ti), a layer (I_b) in which the base (Bi) is made of (Ti), and a layer in which the emitter (Ei) is made of (Ti) on a substrate (S), characterized in that it includes:

- the creation of a resistance (R_{Bi}) in the layer (i_B),
- the creation of a condenser (C_{Bi}) on the substrate (S),
- the mounting in series with the base (Bi) of the transistor (Ti), of the resistance (R_{Bi}) – condenser (C_{Bi}) set, mounted in parallel.

Preferably, the process described in the invention includes the connection of the various bases (Bi) via their set (R_{Bi} – C_{Bi}) to a common base bus. The various emitters (Ei) are preferably connected to a common emitter bus.

The invention will be easier to understand and other advantages will become apparent upon reading the description below in reference to the appended figures, including:

- Figure 1, illustrating a power component architecture according to prior art, using a set of elementary transistors;
- Figure 2, illustrating the change in collector current curves (I_C) as a function of the voltage (V_{CE}) between the collector and the emitter, for different base currents;

- Figure 3, illustrating the change in power gain as a function of the usage frequency of the component;
- Figure 4, illustrating a cross-section of one example of the semiconductor component described in the invention, in which only one transistor (Ti) is depicted;
- Figure 5, illustrating a resistance (R_{Bi}) – condenser (C_{Bi}) set, mounted between the base of a transistor (Ti) and the common base bus:
    - Figure 5a, illustrating a view from above,
    - Figure 5b, illustrating a cross-section along an axis (aa) located at the emitter,
    - Figure 5c, illustrating a cross-section (bc) .
- Figure 6, illustrating the change in power gain as a function of frequency, for non-ballasted, emitter-ballasted and base-ballasted components, respectively,
- Figure 7, illustrating the change in the stability criteria in terms of frequency for the three aforementioned components.

The purpose of the invention is thus to provide a semiconductor component with at least one transistor, in which a resistance (R_B) – condenser (C_B) set, mounted in parallel, is connected in series at the base (B) of the bipolar transistor.

Preferably, the semiconductor component described in the invention is a power component with several transistors coupled in parallel. The various transistors (Ti) are designed on a common semiconductor substrate. The various bases (Bi) of the transistors are connected to a common base bus (bB), via the circuits (R_{Bi}, C_{Bi}) enabling ballasting at the base of each elementary transistor. Likewise, the various emitters are connected to a common emitter bus (bE). The various collectors can be connected to one another via the legs of a collector bridge (PC).

The bipolar transistors used are preferably bipolar transistors with heterojunctions, the functioning principle of which is very close to that of bipolar transistors with homojunctions, but with structural differences that make it possible to obtain better performance.

The semiconductor component described in the invention includes a ballasting resistance (R_B) and a condenser (C_B) mounted in parallel, and the entirety of such an assembly provides impedance that approaches a value that is just as low as the frequency is high. Therefore in microwave frequencies, the result is semiconductor components capable of having very high usage frequencies.

At the same time, gain in power (G) is traditionally defined as the ratio of output power (Ps) of the transistor over the input power (Pi) of the transistor: (G = Ps/Pi). The changes in this parameter (G) with the frequency is provided in Figure 3. Typically, this gain is very high at low frequencies, and therefore a stability criterion (k) is defined such that when it is greater than 1, the transistor is stable (no oscillation) and when it is lower than 1, the mechanism is unstable. This criterion (k) generally increases with frequency. By adding resistance (R_B), the gain (G) is decreased, which makes it possible to significantly decrease the undesirable oscillation phenomena at low frequencies. In the range of frequencies, in the neighborhood of a few GigaHertz, the impedance of the $R_B - C_B$ set decreases to lower than at low frequencies, and the gain (G) therefore does not fall much and we have a mechanism capable of being stable while experiencing a significant power gain (significant G with k of greater than 1).

We are going to describe one example of the component described in the invention, specifically using an original procedural step to create ballasting resistance (R_B).

The semiconductor component described in the invention is intended to produce power and is obtained typically through the coupling of several elementary transistors. This may involve a dozen transistors, each with an emitter surface of approximately 2 x 30 μm^2, in order to obtain an output power of 1W at a frequency of 10 GHz.

We are going to describe the elementary structure of a transistor (Ti) as well as the $R_{Bi} - C_{Bi}$ set associated with it.

Figure 4 depicts a cross-section of a transistor (Ti) created for the component described in the invention.

In general, elementary transistors are developed from a multi-layer structure. Indeed, from a semiconductor substrate (S), an initial sub-collector layer can be produced that is heavily n-enhanced,

for example a Si-enhanced GaAs layer with a concentration of 3 x $10^{18}cm^{-3}$. Above, a collector layer (C) is developed for the transistor by depositing an n-enhanced GaAs layer (concentration typically on the order of 2 x $10^{16}cm^{-3}$), then a base layer (B) of p-enhanced (with carbon) GaAs with a concentration on the order of 7 x $10^{19}cm^{-3}$, and finally a layer for the emitter (E) of n-enhanced GainP, then covered with a more conductive layer of greatly enhanced GaAs (for example with Si and a concentration of 3 x $10^{18}cm^{-3}$). GainP offers the advantage of having a higher band gap than $Ga_{1-x}Al_xA_s$ generally used in others (TBH). Additionally, there are various engraving procedures, either by aqueous chemicals or by dry engraving, that make it possible to selectively engrave the GainP/GaAs pair, and thus engrave the entire emitter layer while stopping at the base with excellent selectivity.

Based on this multi-layer structure, various elements are created, such as a transistor, resistance and a condenser. To this end, the various layers are engraved. Figure 4 is a good illustration of the elementary structure (Ti). In this way, all of the layers are freed locally to produce electric insulations in the sub-collector layer, typically by implanting boron ions to insulate the various transistors from one another and to decrease interference capacities. Likewise, the collector layer is partially freed to make contact points (cc) enabling contact to be established with the collector. These contact points (cc) can be created by AuGe/Ni/Au-type metalization that is well-adapted to material III-V technology. By using a pyramid-like architecture, the transistor base (B) is created by freeing the base layer, on which the emitter is once again freed to create contact points above the base (B). These contact points (cb) can be created by depositing Ti/Pt/Au. Moreover, contact at the emitter can be created through a contact point (ce), and this can also be done with Ti/Pt/Au.

At the same time as the transistors (Ti) are created, a resistance set (R_{Bi}) is created on the initial multi-layer structure, mounted in parallel with condensers (C_{Bi}), and the pairs (R_{Bi}, C_{Bi}) are connected in series between the elementary transistors (Ti) and the base bus (bB).

In this invention, by using base ballasting (stabilization of base currents), resistances are created with higher values than the ballasting resistances at the emitter. Indeed, currents pass through these resistances at the base that are β (β gain in current) times lower, and that dissipate a continuous power that is β times lower. Although the ballasting resistances at the emitter level are typically a few ohms, the resistances (R_B) used in the invention must be on the order of a hundred ohms to avoid the same thermal runaway problems.

The base layer used in this example usually has a superficial resistance of approximately 120 Ω per square, making it possible to use this value to create the resistance (R_B). Therefore, by using semiconductor resistances, the risk of electromigration appearing may be greatly decreased due to lower current densities.

As for the structure of condenser (C_B), it s established at the level of the semiconductor substrate and results in successive deposits of dielectric metal (nitride type)-metal (capacity referred to as metal-insulating-metal).

Figure 5a depicts a view from above of the connection between a transistor (Ti) and a resistance (R_B) – condenser (C_B) circuit, while Figures 5b and 5c each depict a cross-section (aa and bc respectively), of said view from above.

Figure 5a illustrates a transistor (Ti) in which the two collector contacts cc_1 and cc_2 are represented, as well as the emitter contact (ce) connected to the emitter bus (bE). An initial metal bridge (T_{b1}) connects the base of the transistor to the base ballast resistance at a point connected via a bridge (P_{bc}) at the lower frame of the condenser (C_B). A second bridge P_{b2} connects the resistance R_B to the upper frame of the condenser. Such an assembly makes it possible to mount the resistance (R_B) and the condenser (C_B) in parallel. A last point (Pf) establishes the connection between the resistance-condenser circuit and the base bus (bB) connecting all the bases (Bi) of the transistors (Ti) to one another.

The performance obtained in microwave frequencies through the ballasting at the base is now illustrated by the comparison between:

- an elementary transistor with a heterojunction of 2 x 30 μm^2 of emitter surface (HBTSS);
- a transistor identical to the HBTSS, with emitter ballast resistance (6 Ω typically) (HBTBE);
- a transistor as described in the invention that is identical to the HBTSS with a ballast resistance on the base (120 Ω), a condenser in parallel (1.5 pF), with a serial resistance (1 Ω) representing the imperfections of an integrated condenser (metal-insulating-metal) (HBTBB).

Figure 6 depicts the change in power gain as a function of frequency for the three components (HBTSS, HBTBE and HBTBB). It should be noted that the gain at 10 GHz is clearly higher for the transistor without ballast, that the transistor with ballast on the base loses only one decibel compared to the non-ballasted transistor at 10 GHz, and that the ballasted component on the emitter loses approximately 3.2 dB.

Figure 7 depicts the change in the stability criteria (k) as a function of frequency. It should be noted that the component with ballast on the base is the most stable, followed by the non-ballasted component, while the transistor with ballast on the emitter is not stable at all up to 20 GHz.

CLAIMS

1. Semiconductor component, including at least one bipolar transistor with an emitter (E), a base (B) and a collector (C), characterized in that the base (B) is connected in series with a resistance (RB) – condenser (CB) set mounted in parallel.

2. Semiconductor component described in claim 1, characterized in that it includes several bipolar transistors (Ti) mounted in parallel on a substrate (S), in which the bases (Bi) of the transistors are connected via conductor pins to a base bus (bB), where said pins include the R_{Bi}-C_{Bi} sets, the emitters (Ei) of the transistors are connected via conductor pins to an emitter bus (bE), and the collectors (Ci) of the transistors are connected to one another by a collector bridge (PC).

3. Semiconductor component described in either claim 1 or 2, characterized in that the transistors are bipolar transistors with heterojunctions.

4. Semiconductor component described in any of claims 1 to 3, characterized in that the homogenous semiconductor substrate is GaAs.

5. Semiconductor component described in any of claims 1 to 3, characterized in that the substrate is of the semiconductor-on-insulator type.

6. Semiconductor component described in claim 4, characterized in that the materials of which the base and the collector are comprised are p-enhanced GaAs and n-enhanced GaAs, respectively.

7. Semiconductor component described in claim 4, characterized in that the material of which the emitter is comprised is n-enhanced GainP.

8. Use of the semiconductor component described in any of claims 1 to 7, characterized in that it is used within a range of frequencies of greater than approximately 1 GigaHertz.

9. Process of making a semiconductor component with at least one bipolar transistor (Ti), created by stacking at least one layer (I_c) in which the collector (Ci) is made of (Ti), a layer (I_b) in which the base (Bi) is made of (Ti), and a layer (I_e) in which the emitter (Ei) is made of (Ti) on a substrate (S), characterized in that it includes:

- the creation of a resistance (R_{Bi}) in the layer (I_B),

- the creation of a condenser (C_{Bi}) on the substrate (S)

- the mounting, in series, of the base (Bi) of the transistor (Ti), of the resistance (R_{Bi}) – condenser (C_{Bi}) set, mounted in parallel.

10. Procedure for creating the semiconductor component described in claim 9, characterized in that the resistance (R_{Bi}) is created in the layer (I_B).

11. Procedure for creating the semiconductor component described in claim 10, characterized in that the material in the layer (I_B) is carbon-enhanced GaAs.

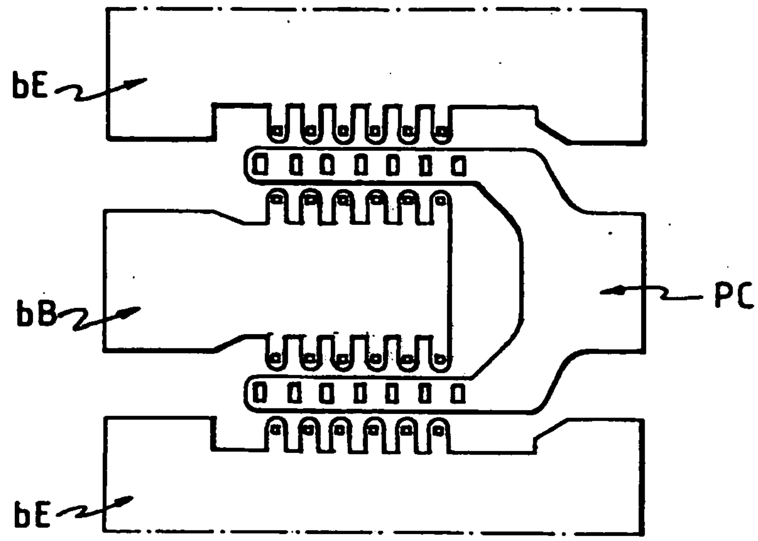


FIG. 1

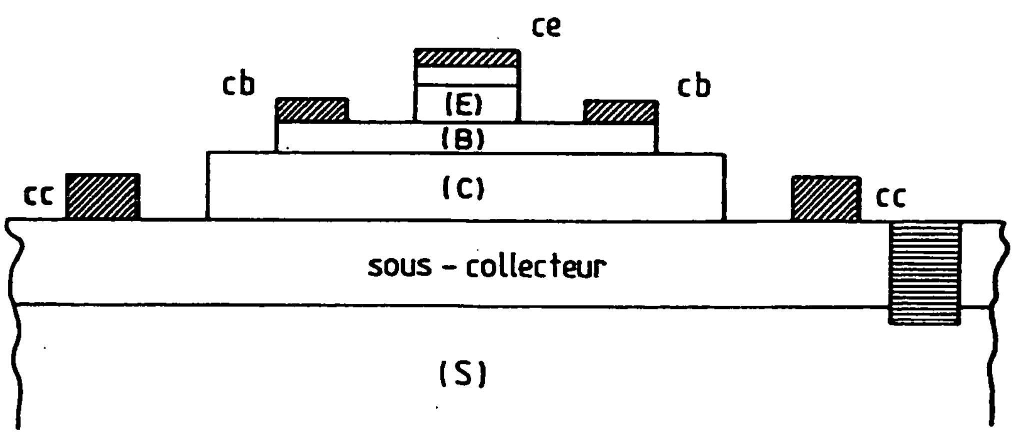


FIG. 4

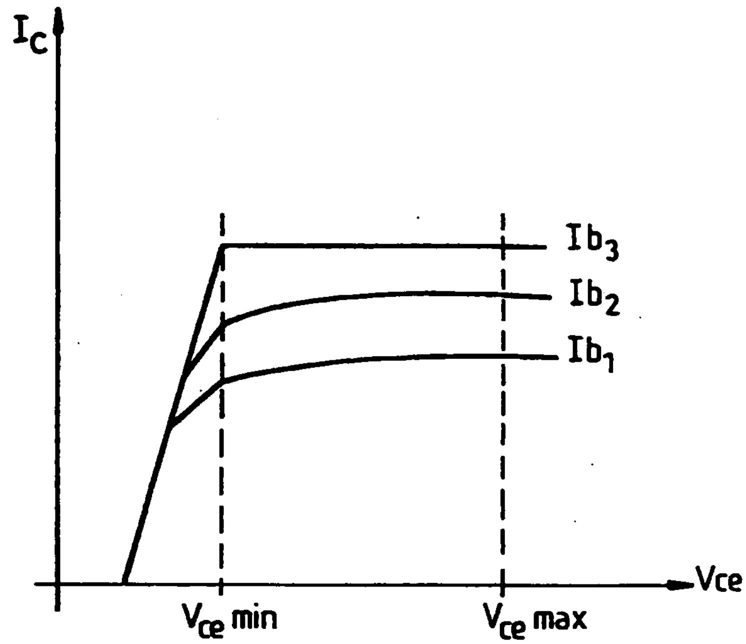


FIG. 2

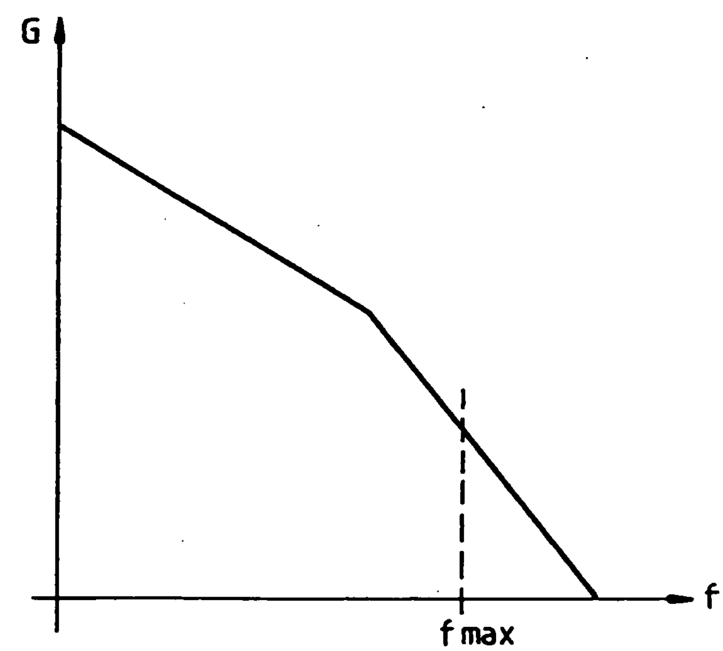


FIG. 3

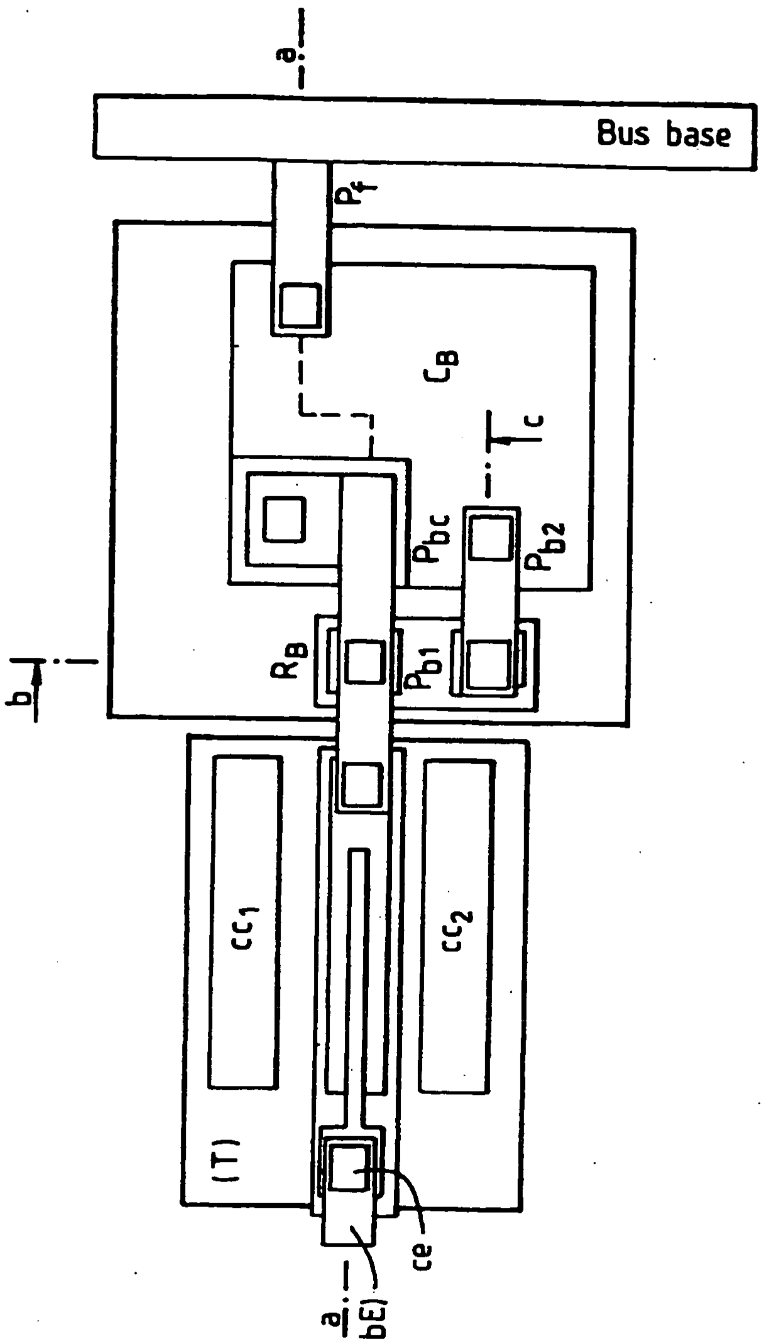
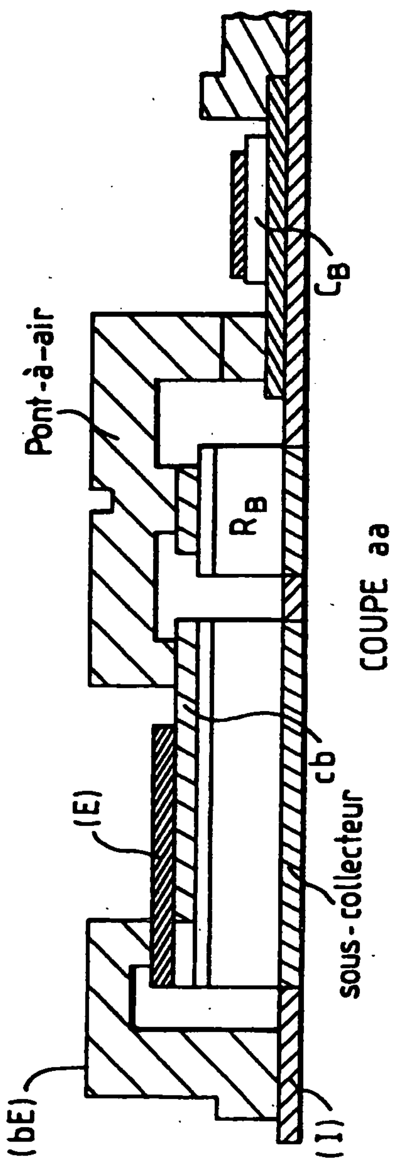
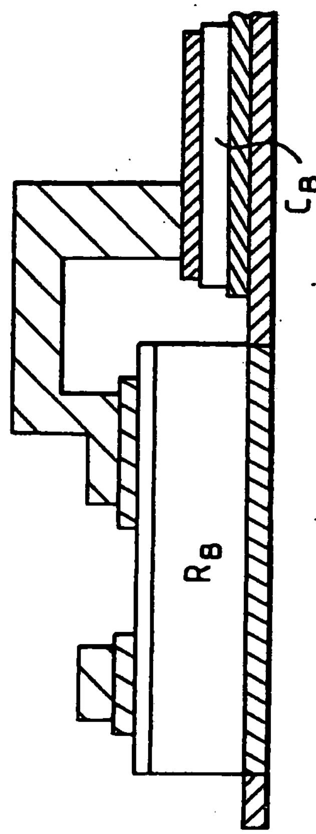


FIG.5a



COUPE aa

FIG.5b



COUPE bc

FIG.5c

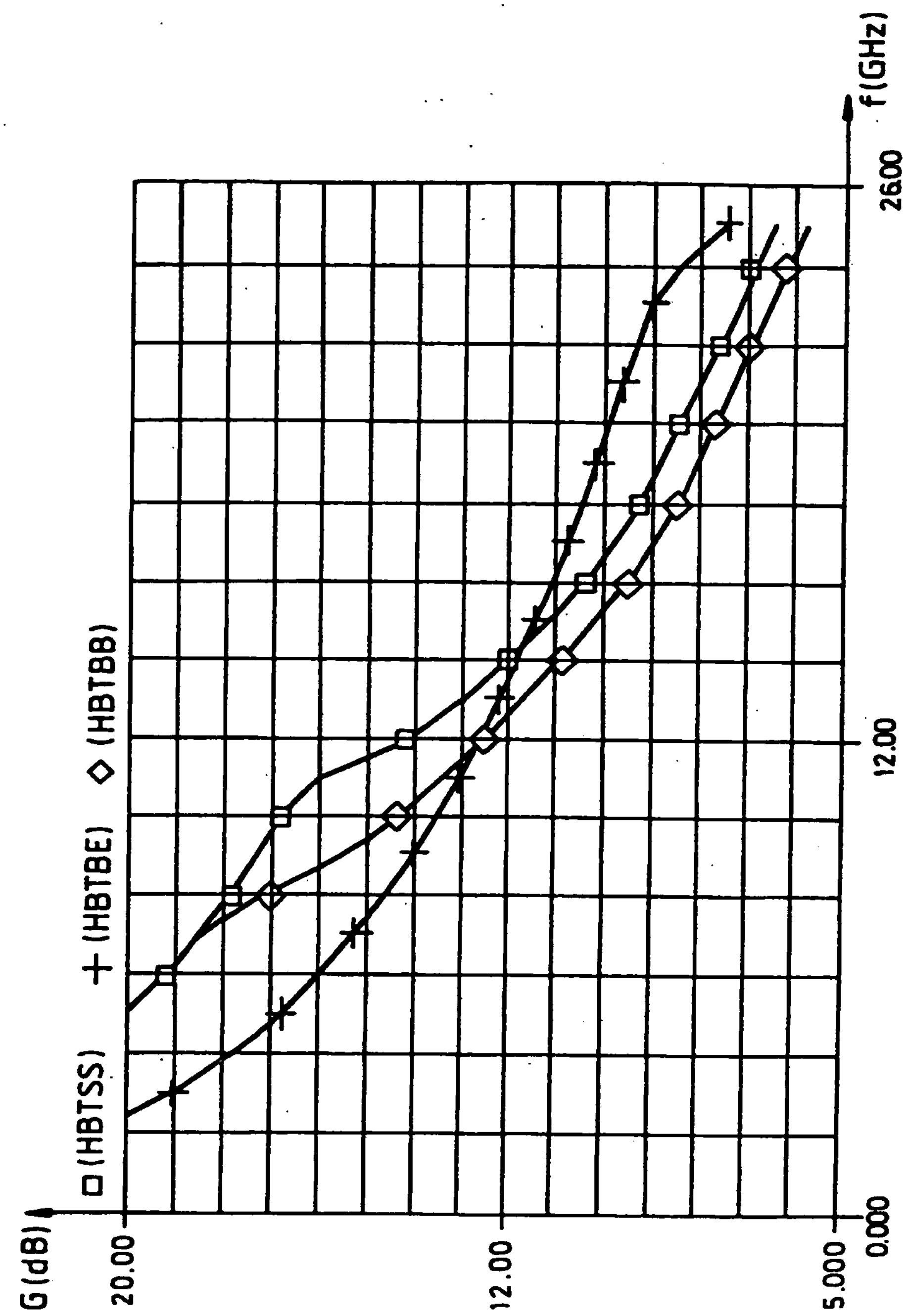


FIG. 6

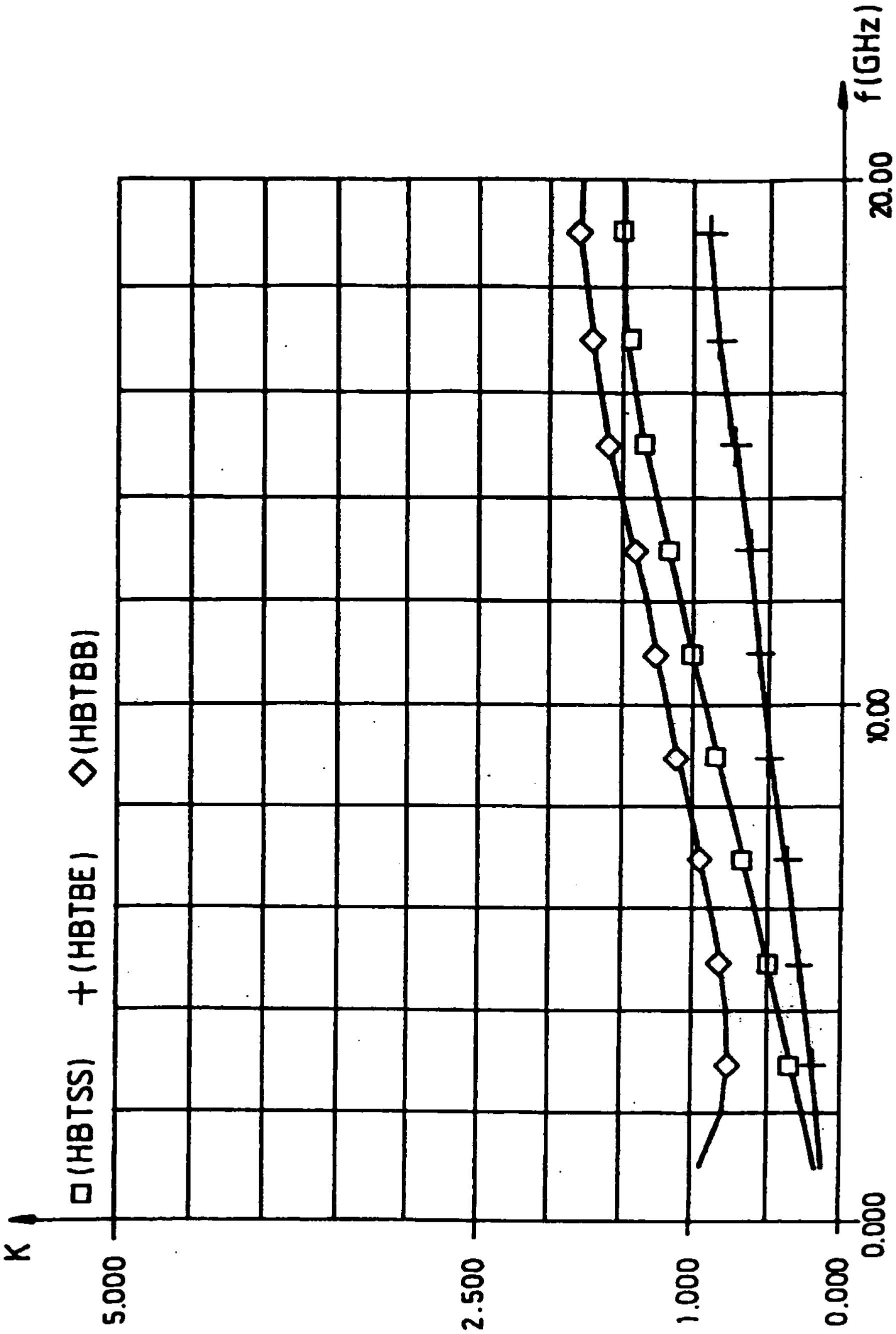


FIG. 7